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Climate change impact of livestock CH_4 emission in India: Global temperature change potential (GTP) and surface temperature response

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ABSTRACT

Two climate metrics, Global surface Temperature Change Potential (GTP) and the Absolute GTP (AGTP) are used for studying the global surface temperature impact of CH_4 emission from livestock in India. The impact on global surface temperature is estimated for 20 and 100 year time frames due to CH_4 emission. The results show that the CH_4 emission from livestock, worked out to 15.3 Tg in 2012. In terms of climate metrics GTP of livestock-related CH_4 emission in India in 2012 were 1030 Tg CO_2e (GTP_{20}) and 62 Tg CO_2e (GTP_{100}) at the 20 and 100 year time horizon, respectively. The study also illustrates that livestock-related CH_4 emissions in India can cause a surface temperature increase of up to 0.7 mK and 0.036 mK over the 20 and 100 year time periods, respectively. The surface temperature response to a year of Indian livestock emission peaks at 0.9 mK in the year 2021 (9 years after the time of emission). The AGTP gives important information in terms of temperature change due to annual CH_4 emissions, which is useful when comparing policies that address multiple gases.

1. Introduction

Methane (CH_4) is the most abundant non-CO_2 greenhouse gas (GHG) and contributes 0.97 W/m^2 of forcing, or about 1/3rd of the forcing from well-mixed GHGs (IPCC, 2014). Although emitted in much less quantity by mass than CO_2, CH_4 can cause significant climate damage because of its high radiative forcing (IPCC 2013; Ripple et al., 2014; Xie et al., 2016). Thus, mitigation of methane emissions can yield large benefits to climate, health, and agriculture.

The livestock sector is a major source of anthropogenic CH_4 emission, with annual contributions of 14.5% to the global CH_4 emission budget (Kebreab et al., 2010; Martin et al., 2010; Gerber et al., 2013). The IPCC has also reported that the global animal sector can cause surface temperature to rise by ~5 m K over 20 year time horizon (IPCC, 2014). More than 90% of livestock CH_4 emission occur through the enteric fermentation process in ruminant animals (Monteny et al., 2006; Kumari et al., 2014). In India, district level assessment has been reported for the year 2003 from livestock, which was 14.3 Tg yr $^{-1}$ (Chhabra et al., 2013). The first Biennial Update Report presented to the United Nations Framework Convention on Climate Change gives an overall estimation of greenhouse gas emission amounting to 2137 Tg in 2010 from India (MOEF, 2015). The agriculture sector was reported to contribute 18% of the total greenhouse gas emissions and methane emission through enteric fermentation was nearly 60% of the agricultural emissions. Thus, bolstering researches to understand the climate change impact of livestock emission is relevant for effective climate mitigation policies and also to promote sustainable livestock farming. Such research is particularly important in livestock dominant countries like India, China, Brazil and USA. For instance, India has the world's largest livestock population (> 500 million), contributing nearly 10–15 Tg CH_4 emission annually (Chhabra et al., 2013; Kumari et al., 2016).

Since the IPCC's first assessment report in 1990, the global warming potential (GWP) has been used as a method for comparing the potential climate impact of different GHGs (Shine et al., 2005). But, the use of GWP has been criticized by many climate scientists because GWP does not explain the magnitude of climate change due to GHGs emission (*i.e.* impact on temperature rise) and the GWP exchange value does not give the exact radiative forcing caused in a longer time frame (Shine et al., 2005; Sarofim et al., 2012). Therefore, Shine et al. (2005) proposed the global surface temperature change potential (GTP) as an alternative metric to GWP to assess climate change impact of GHGs emission. As defined in the IPCC 4th assessment report (IPCC, 2007), the GTP is the ratio between the global mean surface temperature change at a given

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future time horizon following an emission (pulse or sustained emission) of any GHGs relative to a reference gas *r* (*e.g.,* CO_2). The GTP is particularly useful for short lived GHGs such as CH_4 (Peters et al., 2011; Persson et al., 2015). Unlike GWP, the GTP gives climate impact in term of change in temperature and hence, it can be used as a more policy-relevant tool (Shine et al., 2007; Sarofim et al., 2012). The metric could be an instrument designed to weight the various gases in manners that ensure 'equivalence' in climate impact within a chosen time frame (Fuglestvedt et al., 2003; Shine, 2009).

In line with the above discussion, the present research is conducted in India to assess the climate change impact of livestock CH_4 emission flux in terms of global temperature change potential (GTP) and absolute global surface temperature change potential (AGTP). The assessment is conducted at national, state and district levels. This is a first of a kind of study in India in the sense that earlier studies have focused estimating livestock emission only, without any attempt to evaluate the impact of emission on surface temperature change. The impact on surface temperature due to constant rate annual emission from livestock in India is also estimated here. The findings could be significant in terms of impact assessment from Indian livestock and CH_4 emission from Indian livestock. Thus, the study helps not only to predict climate change response, but also a potential rise in global surface temperature due to any anthropogenic emissions sources in future.

2. Methods

A flow chart of the methodology is presented in Fig. 1. The detail procedure is discussed below.

In brief, district-level livestock population data were collected to estimate livestock CH_4 emission in India using the IPCC's Tier 1 approach. The emission is represented in the GTP equivalent for two different time horizon *viz.* 20 and 100 years. Next, the surface temperature response due to CH_4 emission is calculated. A spatial map of livestock CH_4 emission is generated by plotting the emission data in Geographical Information System (GIS).

2.1. Livestock CH_4 emission

A livestock database of 28 states and 7 union territories (UTs) covering all the 649 districts of India were collected from the Department of Animal Husbandry and Statistics, Government of India (BAHS, 2012). The database is divided into four categories *viz.* cattle, buffalo, goat and sheep. Other livestock such as pig, horses, mules, and ponies are not considered due to their small population. The cattle group is further divided into dairy and non-dairy cattle.

CH_4 emission estimation is based on IPCC's Tier 1 approach and livestock category-wise specific emission factors (Table 1) as shown in

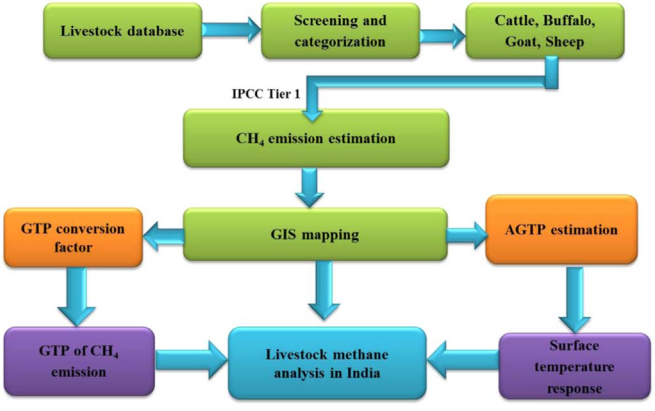

Fig. 1. General framework for estimation of livestock CH_4 emission and its impact on climate change.

Table 1
CH_4 emission factor (kg CH_4 head^{-1} yr^{-1}) for different livestock categories (IPCC, 2006).

Category		Enteric fermentation	Manure management
Cattle	Dairy cattle	58	5
	Non-dairy	27	2
Buffalo		55	4
Sheep		5	2
Goat		5	0.22

Model (1).

$$E_d = \sum_{i=1}^{z} (P_i) \times EF_i \tag{1}$$

where E_d is total CH_4 emission from all the livestock categories (cattle, buffalo, goat and sheep) in d^{th} district, kg CH_4 yr^{-1}; P_i is population of i^{th} category of livestock; and EF_i is specific emission factor for i^{th} category of livestock (kg CH_4 head^{-1} yr^{-1}).

2.2. Global temperature change potential (GTP)

The district-level emission data (estimated through Model 1) is further represented in terms of GTP_{20} and GTP_{100} for 20 and 100 year time horizon. The GTP can be calculated as per Fagodiya et al. (2017).

$$GTP_{dt} = E_d \times GTP_t \tag{2}$$

where GTP_{dt} is GTP of livestock CH_4 emission in d^{th} district at time '*t*' (20 or 100 years), kg CO_2e; E_d is derived from Model (1); GTP_t is GTP at '*t*' time scale, taken as 67 for 20 year (GTP_{20}) and 4 for 100 year time horizon (GTP_{100}) (IPCC, 2014).

2.3. Surface temperature response

The Absolute Global surface Temperature change Potential (AGTP) can provide valuable insights into climate impact assessment in term of potentiality to rise in surface temperature. The AGTP is the temperature change (in Kelvin, K) at a time (*t*) associated with GHG emission (Shine et al., 2005). The AGTP can be estimated for pulse emission per year and sustained emission over the time period (Shine et al., 2005) as shown below (IPCC, 2014; Farquharson et al., 2016). Annual CH_4 emission is multiplied by the AGTP to estimate instantaneous surface temperature response (ΔT) (Giuntoli et al., 2016; Farquharson et al., 2016). Annual ΔT is used to illustrate the direct temperature effects attributed due to an annual rate of livestock CH_4 emission over time.

$$AGTP_{(CH_4)_t} = A_{CH_4} \times \sum_{j=1}^{2} \left[\left(\frac{\alpha \times c_j}{\alpha - d_j} \right) \times \left(e^{-t/\alpha} - e^{-t/d_j} \right) \right] \tag{3}$$

$$\Delta T_t = E_d \times AGTP_{(CH_4)_t} \tag{4}$$

In, Model (3): $AGTP_{(CH_4)_t}$ is absolute global temperature potential of CH_4, K kg^{-1} and *t* is 20 or 100 year time horizon; A_{CH_4} is radiative forcing of CH_4, 2.1 × 10^{-13} W (kg-m^2)$^{-1}$; α is perturbation life or e-folding time of CH_4, 12.4 years; c_j is climate sensitive parameters and d_j response times (IPCC, 2014). c_1 and c_2 are 0.631 and 0.429, respectively; d_1 and d_2 are 8.4 and 409.5 respectively; $e^{-t/\alpha}$ is known as an impulse radiative flux (IRF), *i.e.* changes in instantaneous radiative flux due to pulse emissions of GHGs.

An annual emission (kg) is multiplied by the *AGTP* values to arrive at the potential of temperature change (ΔT) in a given year (annual *AGTP*). In Model (4): ΔT_t is the temperature change response, K; E_d is livestock CH_4 emission, kg yr^{-1} which is based on Model (1).

Model (3) and Model (4) are also used for continuous analysis of AGTP and impact on surface temperature, if we assume a constant rate of CH_4 is emitted from livestock. The analysis worked out to find the potential impact of CH_4 emission on the global surface temperature rise potential from livestock in India.

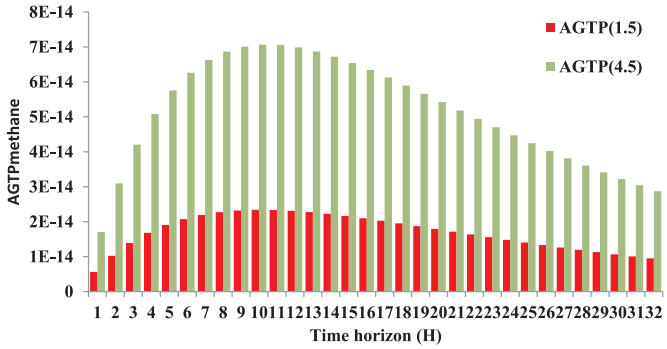

Fig. 2. AGTP under climate sensitivity at two different conditions at climate sensitivity at 1.5 and climate sensitivity at 4.5.

Table 2
CH_4 emission, Tg yr^{-1} from different category of livestock in 2012 from different route.

Livestock category	Enteric fermentation	Manure management	Total
Cattle	7.25	0.59	7.83
Buffalo	5.97	0.43	6.41
Goat	0.68	0.03	0.71
Sheep	0.30	0.13	0.43
Total	14.20	1.18	15.38

2.3.1. Sensitivity analysis

The AGTP calculation is also validated with the sensitivity analysis test carried out for AGTP calculation. Sensitivity analysis not only validates the results, but also the research work in the paper. For the sensitivity analysis, the AGTP recalculated using the Model (3) with a climate sensitivity range of 1.5 and 4.5 to span the IPCC range, where $c_1 + c_2$ is the temperature response per W m^{-2}, and a doubling of CO_2 is 3.7 W/m^2. For climate sensitivity of 1.5, c_j is taken up as $c_1 = 0.241$ and $c_2 = 0.164$. While for climate sensitivity of 4.5, c_j is taken up as $c_1 = 0.728$ and $c_2 = 0.492$. The range of AGTP results shows the sensitivity of Model 3. The results are shown in Fig. 2. In this figure both the results of climate sensitivity of 1.5 and 4.5 follow the same pattern *i.e* after 10 years AGTP attain its peak than it show the decreasing trend. Peak values for AGTP at climate sensitivity of 1.5 are 2.33×10^{-14} and at climate sensitivity of 4.5 is 7.06×10^{-14}. But the AGTP is found to be different as their parameters for calculation are different. Other climatic parameters of d_1 and d_2 can also vary to test the sensitivity of AGTP model. This is not studied in the chapter.

3. Results and discussion

Climate metrics, *i.e.* GTP and AGTP are estimated with the help of the Model (1) to (3). Climate response, *i.e.* surface temperature response (ΔT) due to livestock CH_4 emission flux is estimated using the Model (4). The results are discussed below.

3.1. Livestock CH_4 emission

Wide variations in district and state level livestock populations and hence CH_4 emission is observed in India. At a national level in the baseline year 2012, livestock CH_4 emission in India is 15.3 Tg yr^{-1}. CH_4 emission due to different category of livestock is observed that cattle and buffalo are the major sources of CH_4 emission, 7.83 Tg yr^{-1} and 6.41 Tg yr^{-1} respectively as shown in Table 2. Furthermore, the results also indicate that enteric fermentation is the major contributor to CH_4 emission (92.8%).

However, among the states, Uttar Pradesh, Rajasthan and Madhya Pradesh: these three states alone contribute 36% of national CH_4 emission, due to their large cattle and buffalo population. At a district level, the top 100 emitting districts account for 179 million livestock and 37% of national livestock CH_4 emission. The district with the highest enteric fermentation related emission also tops in manure management related emission. Due to the large variation of CH_4 emission among the districts, we categorized the districts as low, medium, and high intensity zone (Table 3). The low/medium/high CH_4 emission intensity zone are defined as the magnitude of CH_4 emission from the districts such as CH_4 emission from any districts is less than 10 Tg yr^{-1}, it comes under less emission intensity zone. Similarly, the medium and high emission intensity zone defined as the CH_4 emission ranges between 10 and 45 Tg yr^{-1} and > 45 Tg yr^{-1}. The emission intensity zone is useful to focus or classify the district, according to CH_4 emission value. As seen from Table 3, the majority of Indian districts (392) has total livestock emission in the range of 10–45 Gg yr^{-1} (medium intensity zone). On the other hand, each of the 162 and 93 districts contribute total livestock emission less than 10 Gg yr^{-1} (low intensity zone) and more than 45 Gg yr^{-1} (high intensity zone), respectively. At livestock-category level, cattle and buffalo together contribute 93% of total emissions.

A comparison given in Table 4 of the present research findings with previous estimated CH_4 emission from Indian livestock reveals the consistency of result of CH_4 emissions in the present study. Although significant variation exists even among the various published reports. The reason could be the difference in the methodology for CH_4 emission estimation, the baseline year for estimation and different categories of livestock. For example, 2003 is selected as the baseline year for CH_4

Table 3
Key statistics of district level livestock CH_4 emission in India.

Livestock category	Emissions intensity zone	Emission range (Gg yr^{-1})	Districts	CH_4/district	Total CH_4 emission (Gg yr^{-1})	% emission per livestock group
Cattle	Low	< 5	184	2.3	431.4	5.5
	Medium	5–25	403	13.1	5292.4	67.6
	High	> 25	60	35.2	2108.9	26.9
Buffalo	Low	< 5	325	1.4	455.5	7.1
	Medium	5–25	247	12.9	3182.5	49.7
	High	> 25	75	37.0	2771.6	43.2
Sheep	Low	< 1	558	0.1	66.3	15.5
	Medium	1–5	68	2.2	150.3	35.3
	High	> 5	21	10.0	209.8	49.2
Goats	Low	< 1	385	0.4	157.5	22.3
	Medium	1–5	249	1.8	458.6	65.0
	High	> 5	13	6.9	89.5	12.7
Total livestock	Low	< 10	162	3.9	634.1	4.1
	Medium	10–45	392	23.82	9336.8	60.7
	High	> 45	93	58.1	5403.4	35.1

Table 4
Comparison of estimated CH_4, Tg yr^{-1} from livestock sector in the previous works.

Reference	Baseline year	CH_4 emission, Tg yr^{-1}	Methodology used
FAOSTAT (2012)	2012	14.59	IPCC tier1 methodology
Patra (2014)	2010	14.22	IPCC 2006 Tier 1 EFs methodology
EDGAR (2011)	2008	13.75	Emission calculation using a technology based emission factor approach consistently applied for all the countries.
Kumari et al. (2016)	2007	13.85–14.44	IPCC 2006 based EF for CH_4 emission
INCCA (2010)	2007	10.1	IPCC 1996 guidelines
Chhabra et al. (2013)	2003	10.65	Country-specific EFs including age wise for different LS categories
Singh et al. (2012)	2003	9.09	Dietary intake approach
Pathak et al. (2013)	2003	8.33	SF_6 tracer technique
Yamaji et al. (2003)	2000	11.8	IPCC 1996 based EFs for CH_4 emission
Jha et al. (2011)	1994	9.21 ± 2.21	IPCC Tier 2 methodology
ALGAS (1998)	1990	7.56	IPCC 1996 based EFsfor CH_4 emission

emission estimation by Chhabra et al. (2013), Singh et al. (2012) and Pathak et al. (2013). But the findings of the 3 papers vary due to different methodologies used. Respective findings of Chhabra et al. (2013), Singh et al. (2012) and Pathak et al. (2013) were 10.65 Tg, 9.09 Tg and 8.33 Tg. However, in Patra (2014), the CH_4 emission from total categories of livestock was found to be 14.22 Tg through enteric fermentation. About 13.69 Tg of CH_4 contributed from cattle, buffalo, goat and sheep, which was 96.22% of total CH_4 emission. This finding shows the consistency with our result *i.e.* 14.20 Tg in the year 2012. It is also observed that cattle, buffalo, sheep and goat are the key categories of CH_4 emission from livestock as suggested by Jha et al. (2011) and Patra (2014). The Emission Database for Global Atmospheric Research (EDGAR) also published CH_4 emission from livestock up to the year 2008. As per EDGAR, livestock CH_4 emission in India in 2008 was 13.75 Tg. The emission estimates reported by FAOSTAT (2012) (baseline year 2012) and Patra (2014) (baseline year 2010) are slightly lower than the estimate of this present work (15.3. Tg). The reason for the higher estimate of the present analysis could be due to category-wise bifurcation of cattle group in to cattle dairy and cattle non-dairy. Also, revised emission factors for different categories of livestock are used in this study as reported in the IPCC (2006) report.

3.2. GTP of livestock CH_4 emission

The livestock CH_4 emission data is further used to calculate GTP (GTP_{20} and GTP_{100}) at 20 and 100 year time horizon as shown in Fig. 3. At a national level, GTP due to livestock CH_4 emission are 1030 Tg CO_2e (GTP_{20}) and 62 Tg CO_2e (GTP_{100}), respectively. At a state level, GTP_{20} and GTP_{100} varies between 0.01– 184 Tg CO_2e (GTP_{20}) and 0.007 –18.0 Tg CO_2e (GTP_{100}), respectively with the lowest in Mizoram and

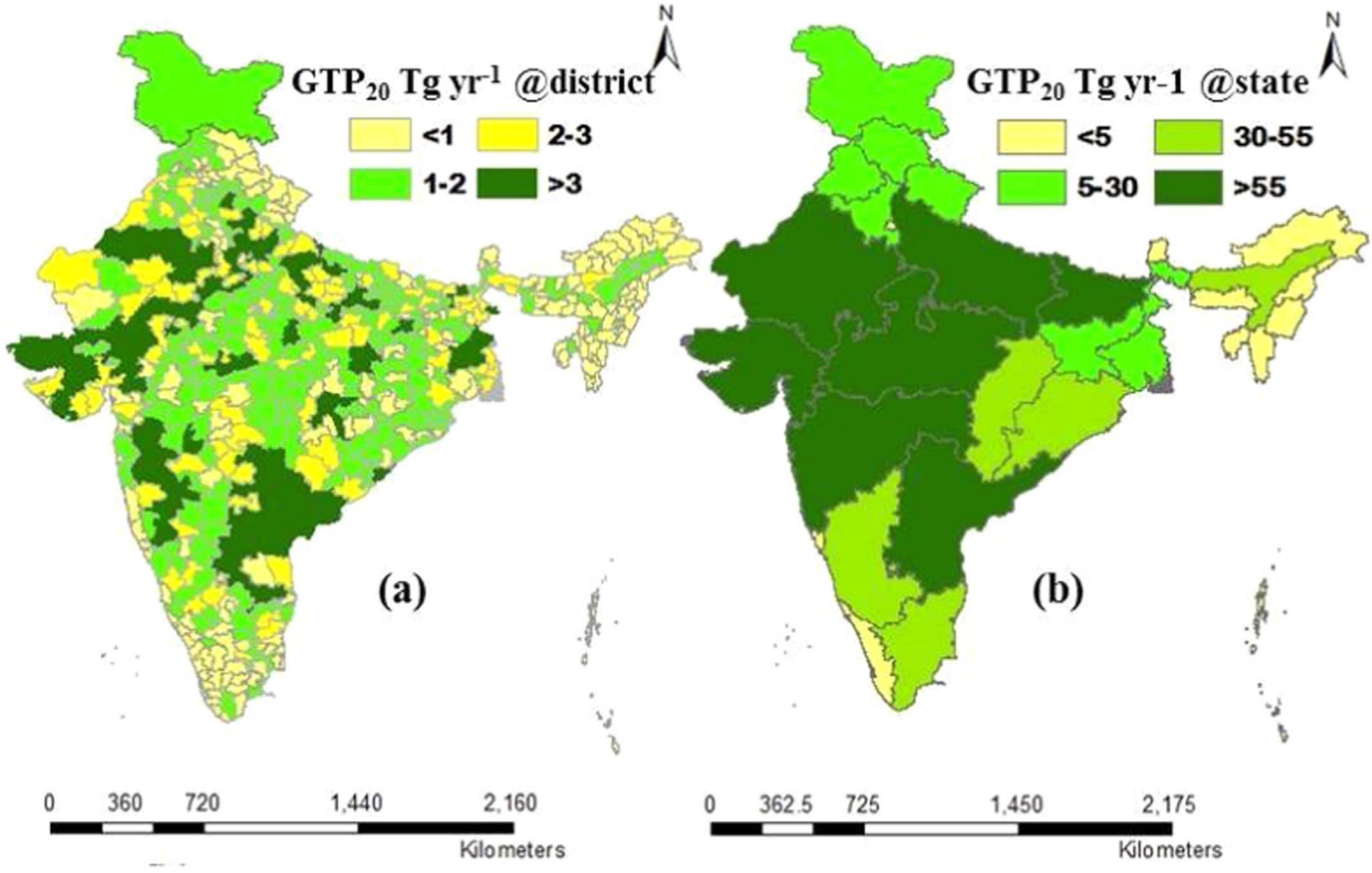

Fig. 3. GTP estimate of livestock CH_4 emission in India: GTP_{20} of CH_4 in Tg CO_2e at (a) district and (b) state level.

Table 5
Comparison between GTP_{20}, GTP_{100}, GWP_{20} and GWP_{100} of estimated CH_4 emission from livestock.

Category	Enteric fermentation				Manure management			
	GTP_{20}	GTP_{100}	GWP_{20}	GWP_{100}	GTP_{20}	GTP_{100}	GWP_{20}	GWP_{100}
Cattle	485.55	28.99	608.75	202.92	39.21	2.34	49.16	16.39
Buffalo	400.23	23.89	501.78	167.26	28.97	1.73	36.32	12.11
Goat	45.32	2.71	56.82	18.94	1.97	0.12	2.47	0.82
Sheep	20.30	1.21	25.45	8.48	8.69	0.52	10.90	3.63
Total	951.40	56.80	1192.80	397.60	78.84	4.71	98.85	32.95

highest in Uttar Pradesh. At a district level, GTP_{20} and GTP_{100} varies between 0.009– 7.5 Tg CO_2e (GTP_{20}) and 3.75 × 10^{-6}– 0.3 Tg CO_2e (GTP_{100}), respectively.

A similar map is observed for GTP_{100}, at district and state level (Fig. 3). It is observed that cattle and buffalo are the major sources of CH_4 emission and hence GTP. The GTP of cattle and buffalo together is estimated at more than 953.9 Tg CO_2e (GTP_{20}) and 56.9 Tg CO_2e (GTP_{100}), respectively. Furthermore, the results also indicate that enteric fermentation is the major contributor to GTP.

The GTPs provide a common unit of measure, which allows analysts to add up emissions estimates of different gases (*e.g.,* to compile a national GHG inventory), and allows policymakers to compare emissions reduction opportunities across sectors and gases (Manning et al., 2009). The different GTP time frames (*e.g.* 20 and 100 years for CH_4 in this study) allow comparisons of the global warming impacts of a gas over a period of time (Boucher et al., 2009; Joos et al., 2013). The larger the GTP, the higher potential for temperature change by a given gas (Shine et al., 2007; Peters et al., 2011). We observed that the climatic impact of CH_4 in GTP_{100} timeframe is smaller compared to GTP_{20}, indicating that as the time horizon becomes longer, short-lived compounds have less effect relative to CO_2 (Shine et al., 2005; Huntingford et al., 2015).

If the GTP climate metric is also compared with the GWP of livestock CH_4 emission, it is found that the results GTP_{20} (1030 Tg CO_2e) to GTP_{100} (62 Tg CO_2e) drops off quickly compared to GWP_{20} (1292 Tg CO_2e) and GWP_{100} (430 Tg CO_2e) (Table 5). The GWP and GTP are fundamentally different by construction and therefore different numerical values can be expected (IPCC, 2014). If we look at the findings of GWP and GTP over the same time frames, GWP_{100} are higher than that of GTP_{100} due to the integrative nature of the GWP (Collins et al., 2013; IPCC, 2014). The GTP calculation is based on assumptions about the climate sensitivity and heat uptake by the ocean and can significantly vary with changes in these assumptions (IPCC, 2014). Like GWP, the GTP values worked out in 'CO_2 equivalents". GTP is a metric which is used with reference to CO_2 and it is equal to the ratio of AGTP of reference gas and AGTP of CO_2. AGTP is the absolute GTP giving temperature change per unit of GHG emission. In case of GTP_{20} and GTP_{100}, the GTP_{20} is 17 times higher than that of GTP_{100}, while GWP_{20} is only 3 times higher than that of GWP_{100}. The major reason that the GTP_{100}/GTP_{20} ratio is much larger than the GWP_{100}/GWP_{20} ratio is because it is an endpoint metric, and GWP is integrative. Accounting for the response time of the climate system would, if anything, make the differences smaller because there is more climate inertia, so the temperature in 100 years hasn't dropped as much as it might have anyway.

3.3. AGTP and surface temperature response (ΔT)

An instantaneous climatic metric such as AGTP can be more meaningful than GWP for climate change impact assessment (Fagodiya et al., 2017).

3.3.1. Annual AGTP estimation and surface temperature response (ΔT)

Here in this study, annual AGTP is estimated using the Model (3). The AGTP is estimated at 4.6 × 10^{-14} K kg^{-1} and 2.3 × 10^{-15} K kg^{-1} for 20 and 100 year timeframe, respectively.

Table 6
Surface temperature response (Δ*T*) due to state level livestock CH_4 emissions.

State	ΔT_{20}, m K	ΔT_{100}, m K
Uttar Pradesh	1.26 × 10^{-1}	6.50 × 10^{-3}
Rajasthan	6.95 × 10^{-2}	3.58 × 10^{-3}
Madhya Pradesh	6.02 × 10^{-2}	3.01 × 10^{-3}
Andhra Pradesh	5.49 × 10^{-2}	2.83 × 10^{-3}
Gujarat	4.89 × 10^{-2}	2.52 × 10^{-3}
Bihar	4.69 × 10^{-2}	2.41 × 10^{-3}
Maharashtra	4.58 × 10^{-2}	2.36 × 10^{-3}
West Bengal	3.51 × 10^{-2}	1.80 × 10^{-3}
Karnataka	3.17 × 10^{-2}	1.63 × 10^{-3}
Odisha	2.38 × 10^{-2}	1.22 × 10^{-3}
Tamilnadu	2.32 × 10^{-2}	1.18 × 10^{-3}
Chhattisgarh	2.17 × 10^{-2}	1.08 × 10^{-2}
Assam	2.13 × 10^{-2}	1.06 × 10^{-2}
Haryana	2.02 × 10^{-2}	1.01 × 10^{-2}
Jharkhand	2.00 × 10^{-2}	9.92 × 10^{-3}
Punjab	1.92 × 10^{-2}	9.56 × 10^{-3}
Jammu and Kashmir	8.82 × 10^{-3}	4.34 × 10^{-3}
Uttarakhand	6.94 × 10^{-3}	3.44 × 10^{-3}
Himachal Pradesh	6.66 × 10^{-3}	3.31 × 10^{-3}
Kerala	3.34 × 10^{-3}	1.66 × 10^{-3}
Tripura	1.86 × 10^{-3}	9.26 × 10^{-4}
Meghalaya	1.80 × 10^{-3}	8.97 × 10^{-4}
Arunachal Pradesh	8.87 × 10^{-4}	4.40 × 10^{-4}
Manipur	6.74 × 10^{-4}	3.34 × 10^{-4}
Delhi	6.28 × 10^{-4}	3.12 × 10^{-4}
Nagaland	4.41 × 10^{-4}	2.19 × 10^{-4}
Sikkim	3.01 × 10^{-4}	1.49 × 10^{-4}
Goa	1.15 × 10^{-4}	5.75 × 10^{-5}
Mizoram	8.54 × 10^{-5}	4.23 × 10^{-5}
UTs[a]	0.000005–0.00012	0.000002–0.00006
India	**0.70**	**0.036**

[a] ΔT for Union Territories with the highest in Puducherry and lowest in Daman and Diu.

Table 7
Global surface temperature response due to district-level livestock CH_4 emissions.

Surface temperature response (Δ*T*)	Δ*T* range, m K	No. of district
ΔT_{20}	< 0.0001	69
	0.0001–0.0005	105
	0.0005–0.001	180
	> 0.001	253
ΔT_{100}	< 0.00001	92
	0.00001–0.00005	263
	0.00005–0.0001	196
	> 0.0001	96

Using the AGTP values, surface temperature response (Δ*T*) is estimated as per Model (4). The contribution of methane emission from the country to the Δ*T* for 20 and 100 year time frame are 0.69 m K and 0.036 m K, respectively (Table 6). Livestock CH_4 emission from different states can contribute to the surface temperature response (ΔT_{20}), ranging between 8.45 × 10^{-5} to 1.25 × 10^{-1} m K in 20 year time horizon. While in 100 year time horizon, ΔT_{100} varies from 4.23 × 10^{-5} to 6.50 × 10^{-3} m K. The highest global surface temperature

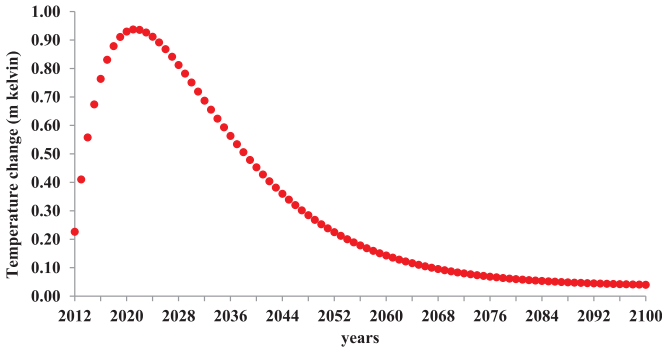

Fig. 4. Year by year surface temperature response (ΔT) due to single year CH_4 emission, Tg yr^{-1}.

response is observed resulting from emissions in Uttar Pradesh, with the lowest response resulting from emissions in Mizoram. The above statements clear that although the global surface temperature response is global but the contribution from livestock in different state and districts level are different.

Temperature changes that result from the annual CH_4 emission at district level are also estimated. At 20 year time horizon, the ΔT_{20} varies from 1.53×10^{-7} to 0.005 m K among the districts of India. However, in 100 year time horizon, the ΔT_{100} varies from 7.66×10^{-9} to 0.0002 m K (Table 7).

Due to high radiative forcing, CH_4 can cause large impacts on climate change on short timescales, but due to its short lifetime, that impact decreases more quickly than for longer lived gases. The livestock emission in India have the potential to cause of surface temperature rise up to 0.69 m K and 0.036 m K over 20 and 100 year time period, respectively. Thus the surface temperature response gives significant information that livestock sector even at small scale can lead to significant climate change.

3.3.2. Continuous AGTP analysis and surface temperature response (ΔT)

This is showing the year-by-year response from a single year's emission of CH_4 from livestock, its impact on surface temperature is estimated using the annual AGTP calculation. The surface temperature change by the year (ΔT) is shown in Fig. 4. It is estimated that the surface temperature will keep rising till 2021 reaching the peak temperature rise (ΔT) 0.937 m kelvin and would start decreasing thereafter. After few years of span beyond the year 2084 the surface temperature response would asymptotically attain steady state. The continuous AGTP calculation is useful for policy makers when comparing multiple greenhouse gases.

Climatic impact assessment have been facing difficulties when comparing the effect of short and long lived GHGs. The GWP and GTP of long lived gases are same (Huntingford et al., 2015). However, for short lived GHGs, the GWP does not account the radiative forcing for a short period. Therefore, the GTP have been proposed for comparison of impact of GHGs emissions on temperature changes at a specific time in future rather than the radiative forcing over a period of time (Manning et al., 2009). Hence, we can say that the GTP compares temperatures at the end of a given time period due to GHGs emissions. In comparison to GWP, GTP extends the information from radiative forcing to rise in the surface temperature relative to that of CO_2 (IPCC, 2014). The GTP further extends the cause-effect chain by adding the temperature impact assessment in comparison to GWP and hence more relevant that by comparing temperature changes (Shine et al., 2007). The GTP is a function of time and used for analyzing the economic benefits from emission reduction. Therefore, it is useful to develop cost effective policy for mitigation policies targeting temperature reduction.

3.4. Uncertainty analysis

The CH_4 emission estimation model relies on the input data of livestock population and specific emission factors for CH_4 emission from different types of livestock categories. Each of these can be a source of uncertainty. FAO (2012) also calculated CH_4 emission from livestock for the year 2012 using the livestock census and IPCC emissions factors. The findings of FAO and our calculation matched except in the case of cattle where FAO underestimated the results. The variation may be due to the differences in the population dataset. In the present study, data is taken from the reports published by Government of India (BAHS, 2014) and emission factors are collected from the IPCC 2006 report (IPCC, 2006). There could be uncertainties in the actual livestock database as only 5% of the total livestock population is used for sampling purposes during the census, which is then aggregated into 100% data. There may be manual errors, for example population counting and sample collection in the livestock census. In addition, CH_4 emission estimation is done using IPCC Tier 1 methodology. In IPCC three types of methodologies are proposed: Tier 1 (basic method), Tier 2 (intermediate method) and Tier 3 (complex method). Tiers 2 and 3 are sometimes referred to as higher tier methods and have less uncertainty. However, the IPCC Tier 1 method, designed for all categories, is readily available for national or international level in combination with default emission factors. Therefore, it is feasible for all countries. As found by Patra (2014) Tier 1 method overestimates the CH_4 emission by 15% compared to Tier 2 estimate. But, country-specific or even smaller region-specific emission factors would bring more precise information. However, such issues could not be considered in the present work and would require further investigation.

4. Conclusion

This research identified regions with high livestock density, high CH_4 emission, high GTP and surface temperature response up to district level in India. The total livestock CH_4 emission in India in 2012 is 15.3 Tg, and nearly 92% of the emission occur *via* enteric fermentation process. In GTP terms, the total CH_4 emission in India is 1030 Tg GTP_{20} CO_2e and 62 Tg GTP_{100} CO_2e at 20 and 100 year time horizon, respectively. The livestock emission in India has the potential to cause the surface temperature rise up to 0.69 m K and 0.036 m K over 20 and 100 year time period, respectively. At a state level, the emission can cause the surface temperature response (ΔT) to vary from 8.49×10^{-5} to 1.25×10^{-1} m K in 20 year time horizon and from 4.23×10^{-5} to 6.25×10^{-2} m K in 100 year time horizon. On the other hand, at district level, the ΔT varies from 1.53×10^{-7} to 0.005 m K in 20 years and from 7.66×10^{-9} to 0.0002 m K in 100 years' time frame.

CH_4 has a high radiative forcing and a short lifetime. A high radiative forcing means a large impact, but a short lifetime means that impact isn't as long-lived as for CO_2. Between two time frames of 20 years and 100 years, the numeric values of GTP and AGTP follow the decreasing trend. The GTP values of CH_4 for 20 and 100 years are 67 and 4 respectively. The AGTP values for the same time horizons are 4.6×10^{-14} K kg^{-1} and 2.3×10^{-15} K kg^{-1}. GTP is a metric which is used in comparing multiple gases with reference to CO_2 whereas AGTP is the absolute GTP giving temperature change per unit of GHG emission. Temperature indices like GTP and AGTP both give the surface temperature change and response using pulse emission. GTP of any greenhouse gas is equal to the ratio of AGTP of given gas and AGTP of CO_2. The AGTP measures the temperature change at some future time after the emission which depends upon the climate sensitivity and ocean uptake of heat by the ocean. The climate sensitivity response fluctuates with the time horizon and extending the time horizon may substantially modify GTP and AGTP. Therefore, a decreasing trend is followed in the AGTP with increasing the time horizon from 20 years to 100 years. Hence, GTP values also decreases with the year. The AGTP can be used to study the impact on surface temperature due to GHG

emission over a period of time. This finding helps to study the impact on surface temperature from livestock emission, which can cause climate damage over a short period of time, even emitted in small quantity.

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References

Asian Development Bank, 1998. ALGAS, Asia Least-cost Greenhouse Gas Abatement Strategy, India. United Nations development Programme, Manila, The Philippines.
BAHS, 2012. Ministry of Agriculture and Farmers Welfare Department of Animal Husbandry, Dairying and Fisheries. India.
BAHS, 2014. Ministry of Agriculture and Farmers Welfare Department of Animal Husbandry, Dairying, and Fisheries. India.
Boucher, O., Friedlingstein, P., Collins, B., Shine, K.P., 2009. The indirect global warming potential and global temperature change potential due to methane oxidation. Environ. Res. Lett. 4, 044007.
Chhabra, A., Manjunath, K.R., Panigrahy, S., Parihar, J.S., 2013. Greenhouse gas emissions from Indian livestock. Clim. Change 117, 329–344.
Collins, W.J., Fry, M.M., Yu, H., Fuglestvedt, J.S., Shindell, D.T., West, J.J., 2013. Global and regional temperature-change potentials for near-term climate forcers. Atmos. Chem. Phys. 13, 2471–2485.
EDGAR, 2011. EDGARv4.2, EDGARv4.2FT2010, extrapolation using NIR/CRF of UNFCCC. (Accessed on March, 2017).
Fagodiya, R.K., Pathak, H., Kumar, A., Bhatia, A., Jain, N., 2017. Global temperature change potential of nitrogen use in agriculture: a 50-year assessment. Sci. Rep. 7, 44928.
FAO, 2012. Food and Agriculture Organization of the United Nations. Available at: faostat.fao.org.
FAOSTAT, 2012. Food and Agriculture Organization of the United Nations. (Available at) http://faostat.fao.org. (Accessed on 23 July 2017).
Farquharson, D., Jaramillo, P., Schivley, G., Klima, K., Carlson, D., Samaras, C., 2016. Beyond global warming potential: a comparative application of climate impact metrics for the life cycle assessment of coal and natural gas based electricity. J. Ind. Ecol. 1–17.
Fuglestvedt, J.S., Berntsen, T.K., Godal, O., Sausen, R., Shine, K.P., Skodvin, T., 2003. Metrics of climate change: assessing radiative forcing and emission indices. Clim. Change 58, 267–331.
Gerber, P.J., Steinfeld, H., Henderson, B., Mottet, A., Opio, C., Dijkman, J., Falcucci, A., Tempio, G., 2013. Tackling Climate Change through Livestock – a Global Assessment Of Emissions and Mitigation Opportunities. Food and Agriculture Organization of the United Nations (FAO), Rome.
Giuntoli, J., Agostini, A., Caserini, S., Lugato, E., Baxter, D., Marelli, L., 2016. Climate change impacts of power generation from residual biomass. Biomass- Bioenergy 89, 146–158.
Huntingford, C., Lowe, J.A., Howarth, N., Bowerman, N.H., Gohar, L.K., et al., 2015. The implications of carbon dioxide and methane exchange for the heavy mitigation RCP2.6 scenario under two metrics. Environ. Sci. Policy 51, 77–87.
INCCA, 2010. India: Greenhouse Gas Emissions 2007, Indian Network for Climate Change. Assessment, Ministry of Environment and Forests. Government of India.
IPCC, 2013. Climate Change: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the IPCC. Cambridge University Press, Cambridge and New York.
IPCC (Intergovermental Panel on Climate Change), 2014. Climate change 2014. IPPC Fifth Assessment Report. IPCC, Geneva, Switzerland.
IPCC, 2006. IPCC Guidelines for national greenhouse gas inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S, Buendia L., Miwa K., Ngara T., and Tanabe K. (eds.), Published IGES, Japan.
IPCC, 2007. Climate Change 2007-the Physical Science Basis: Working group I Contribution to the Fourth Assessment Report of the IPCC. 4 Cambridge University Press.
Jha, A.K., Singh, K., Sharma, C., Singh, S.K., 2011. Assessment of methane and nitrous oxide emissions from livestock in India. J. Earth Sci. Clim. Change 02, 1–12.
Joos, F., Roth, R., Fuglestvedt, J.S., Peters, G.P., Enting, I.G., Bloh, W.V., et al., 2013. Carbon dioxide and climate impulse response functions for the computation of greenhouse gas metrics: a multi-model analysis. Atmos. Chem. Phys. 13, 2793–2825.
Kebreab, E., Strathe, A., Fadel, J., Moraes, L., France, J., 2010. Impact of dietary manipulation on nutrient flows and greenhouse gas emissions in cattle. R. Bras. Zootec. 39, 458–464.
Kumari, S., Dahiya, R.P., Kumari, N., Sharawat, I., 2014. Estimation of methane emission from livestock through enteric fermentation using system dynamic model in India. Int. J. Environ. Res. Dev. 4, 347–352.
Kumari, S., Dahiya, R.P., Naik, S.N., Hiloidhari, M., Thakur, I.S., Sharawat, I., Kumari, N., 2016. Projection of methane emissions from livestock through enteric fermentation: a case study from India. Environ. Dev. 20 (31), 44.
Manning, M., Reisinger, A., Bodeker, G., 2009. Global Warming Potentials and Alternate Metrics. New Zealand Climate Change Research Centre.
Martin, C., Morgavi, D.P., Doreau, M., 2010. Methane mitigation in ruminants: from microbe to the farm scale. Animal 4, 351–365.
MOEF, 2015. India First Biennial Update Report to the United Nations Framework Convention on Climate Change. Ministry of Environment, Forest and Climate Change, Government of India.
Monteny, G.J., Bannink, A., Chadwick, D., 2006. Greenhouse gas abatement strategies for animal husbandry. Agric. Ecosyst. Environ. 112, 163–170.
Pathak, H., Upadhyay, R.C., Muralidhar, M., Bhattacharyya, P., Venkateswarlu, B., 2013. Measurement of Greenhouse Gas Emission from Crop, Livestock and Aquaculture. Indian Agricultural Research Institute, New Delhi, pp. 101.
Patra, A.K., 2014. Trends and projected estimates of GHG emissions from Indian livestock in comparisons with GHG emissions from world and developing countries. Asian Australas. J. Anim. Sci. 27, 592–599.
Persson, U.M., Johansson, D.J., Cederberg, C., Hedenus, F., Bryngelsson, D., 2015. Climate metrics and the carbon footprint of livestock products: where's the beef? Environ. Res. Lett. 10, 034005.
Peters, G.P., Aamaas, B., Berntsen, T., Fuglestvedt, J.S., 2011. The integrated global temperature change potential (iGTP) and relationships between emission metrics. Environ. Res. Lett. 6, 044021.
Ripple, W.J., Smith, P., Haberl, H., Montzka, S.A., McAlpine, C., Boucher, D.H., 2014. Ruminants, climate change and climate policy. Nat. Clim. Change 4, 2–5.
Sarofim, M.C., 2012. The GTP of methane: modeling analysis of temperature impacts of methane and carbon dioxide reductions. Environ. Model. Assess. 17, 231–239.
Shine, K.P., 2009. The global warming potential—the need for an interdisciplinary retrial. Clim. Change 96, 467–472.
Shine, K.P., Berntsen, T.K., Fuglestvedt, J.S., Bieltvedt, S.R., Stuber, N., 2007. Comparing the climate effect of emissions of short- and long-lived climate agents. Philos. Trans. R. Soc. A 365, 1903–1914.
Shine, K.P., Fuglestvedt, J.S., Hailemariam, K., Stuber, N., 2005. Alternatives to the global warming potential for comparing climate impacts of emissions of greenhouse gases. Clim. Change 68, 281–302.
Singh, S., Kushwaha, B.P., Nag, S.K., Bhattacharya, S., Gupta, P.K., Mishra, A.K., Singh, A., 2012. Assessment of enteric methane emission of Indian livestock in different agro-ecological regions. Curr. Sci. 102, 1017–1027.
Xie, B., Zhang, H., Yang, D.D., Wang, Z.L., 2016. A modeling study of effective radiative forcing and climate response due to increased methane concentration. Adv. Clim. Change Res. 7, 241–246.
Yamaji, K., Ohara, T., Akimoto, H., 2003. A country-specific, high-resolution emission inventory for methane from livestock in Asia in 2000. Atmos. Environ. 37, 4393–4406.